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Suppression of vortex motion in $La_{1.85}Sr_{0.15}CuO_4$ with the splayed configuration of columnar defects

X.Fan[a] *, M.Terasawa[a], T.Mitamura[a], T.Kohara[a], K.Ueda[a], H.Tsubakino[a], T.Kambara[b], Y.Awaya[b], M.Matsuda[b], G.Tatara[c], K.Fukushima[d] and N.Takezawa[d]

[a]Himeji Institute of Technology, 2167 Shosha, Himeji, Hyogo 671-22, Japan

[b]The Institute of Physical and Chemical Research (RIKEN), Wako 351-01, Japan

[c]Osaka University, Toyonaka, Osaka 560, Japan

[d]Toshiba Research and Development Center, 4-1 Ukishima-cho, Kawasaki-ku,Kawasaki 210, Japan

Remarkable enhancements of the critical current density J_c were obtained in polycrystalline $La_{1.85}Sr_{0.15}CuO_4$ with the splayed configuration of the columnar defects which were introduced by 3.5 GeV Xe ion irradiation with splay angles $\theta = 0°$, $\pm 5°$ and $\pm 10°$. In addition J_c increased with the irradiation dose from 1.0×10^{11} to 3.0×10^{11} ions/cm^2. Larger upward shift of the irreversibility line for the splayed configuration, in comparison with conventional parallel configuration, was observed. The results suggest that the vortex motion in $La_{1.85}Sr_{0.15}CuO_4$ is suppressed effectively by the splayed irradiation.

1. INTRODUCTION

A large enhancement of the critical current density and the expansion of the irreversible regime have been obtained in the Bose glass [1] and the splayed glass systems [2, 3]. It has been suggested theoretically that if the splay is small, the splayed glass leads to even larger J_c and a smaller creep rate [4]. However the effect of the splayed glass is two-fold [3]: It can either suppress the vortex motion or give rise to the easier jumps of vortex from one column to another.

Recently we presented some of the preliminary results on flux pinning and flux creep in $La_{1.85}Sr_{0.15}CuO_4$ with the splayed configuration of columnar defects [5]. In this paper, we will report the results of the critical current density J_c and the irreversibility lines (IRL's) for $La_{1.85}Sr_{0.15}CuO_4$ with the Bose glass and the splayed glass.

2. EXPERIMENTAL

Sintered polycrystalline $La_{1.85}Sr_{0.15}CuO_4$ (LSCO) pellet was prepared by conventional ceramic methods as described elsewhere [6]. This pellet was sliced into several rectangular specimens of size $3\times3\times0.1$ mm^3. The irradiations were performed with 3.5 GeV $^{136}Xe^{31+}$ ions by a ring cyclotron at RIKEN in Japan. The splayed irradiations were performed at five incident angles: $\theta = 0°$, $\pm 5°$ and $\pm 10°$. Here θ means the angle between ion irradiation and the direction along the shortest dimension z (0.1 mm) of the LSCO specimens. The total irradiation doses were 1.0×10^{11} and 3.0×10^{11} ions/cm^2. Two doses are corresponding to dose-equivalent field B_ϕ = 2.0 and 6.0 T, respectively.

All the measurements were carried out so that the shortest dimension z-axis of each specimen was parallel to the applied magnetic fields in a SQUID magnetometer (Quantum Design).

3. RESULTS AND DISCUSSION

Fig.1 shows the magnetic hysteresis loops of the irradiated LSCO with splayed and parallel columns and the unirradiated specimens at 5 K. The splayed irradiated LSCO with B_ϕ= 6.0 T has the maximum irreversible area of magnetization. As the critical

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current density J_c calculated using the Bean model is proportional to $\Delta M=M^+-M^-$, we could obtain the maximum value of J_c for the splayed irradiated LSCO (B_ϕ=6.0 T) at all applied fields in Fig.1. In addition, in the case of splayed irradiation, J_c increases with B_ϕ from 2.0 to 6.0 T.

Fig. 2 shows the ratio between the Meissner and the shielding fractions (M_{fc}/M_{zfc}). It reveals the least ratio for the splayed irradiated and the largest ratio for the unirradiated LSCO.

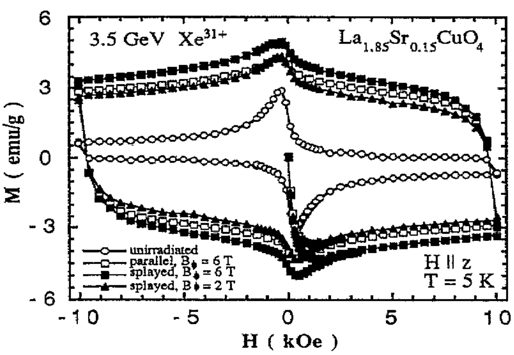

Figure 1. Magnetic hysteresis loops of the unirradiated and the irradiated LSCO with the Bose glass and the splayed glass systems at 5 K.

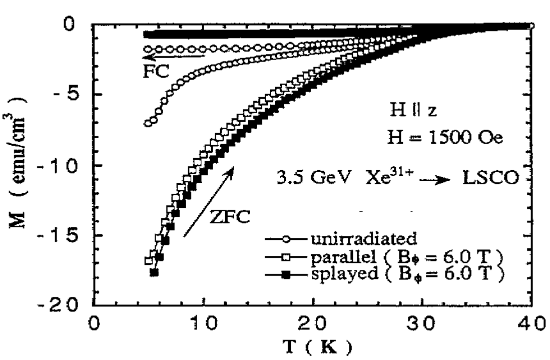

Figure 2. Shielding effect and Meissner effect for the unirradiated and the irradiated LSCO with the Bose glass and the splayed glass systems under the applied field of H =1500 Oe.

From the data of ZFC (zero field cooled) and FC (field cooled) under a series of applied magnetic fields, the irreversibility lines (IRL) are obtained for the splayed, the parallel irradiated and the unirradiated LSCO as shown in Fig.3. The IRL for the splayed irradiated LSCO has a larger upward shift in comparision with the parallel irradiated one. For the both of the irradiated specimens, IRL have definite structured shapes and could be divided into two sections by a characteristic temperature T' = 35.5 K, below which the effective influence of columnar configuration is evident.

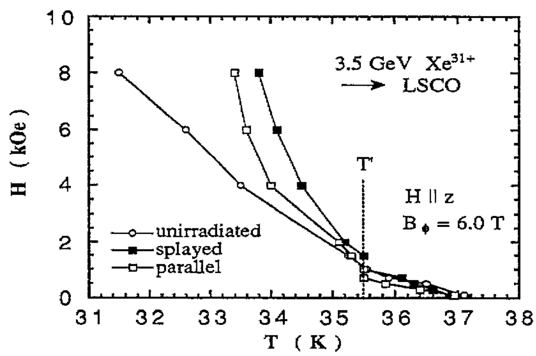

Figure 3. The irreversibility lines (IRL) for the unirradiated and the irradiated LSCO with the Bose glass and the splayed glass systems.

Upward shift of IRL in the splayed glass with respect to the Bose glass is an evidence for a strong dependence on columnar configuration. Stronger vortex pinning and the suppression of vortex motion in the splayed glass are confirmed.

Enhancement of the magnetization, J_c and, also, the IRL observed in the splayed irradiated LSCO suggests that a suppression of vortex motion due to entanglement with splayed columnar defects is more effective in polycrystalline LSCO.

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